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Multilepton SUSY signals from R -parity violation at the Tevatron

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Abstract

The expected trilepton signals from $p\bar{p} \rightarrow \chi_1^\pm \chi_2^0 \rightarrow (\chi_1^0 \ell^\pm \nu)(\chi_1^0 \ell'^+ \ell'^-)$ will be converted into hadronically quiet multilepton signals, if the two final χ_1^0 have leptonic R -parity-violating (RPV) decays $\chi_1^0 \rightarrow \ell \ell' \nu$. We make illustrative calculations of the acceptance for these spectacular RPV signals, and point out that distinctive multilepton signals are possible even when the R -conserving trilepton signals are blocked by the “spoiler mode” $\chi_2^0 \rightarrow h^0 \chi_1^0$. Other channels such as $p\bar{p} \rightarrow \chi_1^\pm \chi_2^0 \rightarrow (\chi_1^0 \ell^\pm \nu)(\chi_1^0 \nu \nu)$, $p\bar{p} \rightarrow \chi_1^\pm \chi_1^0 \rightarrow (\chi_1^0 \ell \nu) \chi_1^0$ and $p\bar{p} \rightarrow \chi_1^+ \chi_1^- \rightarrow (\chi_1^0 \ell^+ \nu)(\chi_1^0 \ell'^- \nu)$ can also give quiet multileptons from RPV. We investigate these signals in the context of supersymmetric models with radiative electroweak symmetry breaking, using examples in the low- $\tan \beta$ λ_t fixed-point region.

There is intense interest in searching for signatures of Supersymmetry (SUSY) at the Fermilab Tevatron $p\bar{p}$ collider, where the highest present CM energy $\sqrt{s} = 1.8\text{--}2$ TeV is accessed. An important possibility is the pair production of charginos and neutralinos [1], whose leptonic decay modes lead to many promising signatures [2–6]. Recently, much theoretical [3,6] and experimental [7,8] attention has centered on trileptons from the production/decay sequence

$$p\bar{p} \rightarrow \chi_i^\pm \chi_2^0 \rightarrow (\chi_1^0 \ell^\pm \nu)(\chi_1^0 \ell'^+ \ell'^-) . \quad (1)$$

Here χ_i^\pm and χ_2^0 are charginos and neutralinos (i, j denote mass ordering) and χ_1^0 is the lightest SUSY particle (LSP); see Figs. 1(a) and 1(b). These trilepton events are distinctively “quiet” (little accompanying hadronic excitation); measurable rates are predicted for interesting ranges of SUSY parameters, but are lost in certain parameter regions e.g. where the “spoiler mode” $\chi_2^0 \rightarrow \chi_1^0 h$ is kinematically accessible and suppresses all other χ_2^0 decays (h being the lightest Higgs scalar), or where one of the leptons is constrained to be soft and becomes undetectable [3,6].

The popular scenario above assumes the LSP is stable and therefore practically invisible, due to R -parity conservation (RPC). The picture changes dramatically with R -parity violation (RPV) [9]. In particular, if explicit RPV occurs through $L_i L_j \bar{E}_k$ terms in the superpotential, the LSP will decay via $\chi_1^0 \rightarrow \ell \ell' \nu$ to a neutrino plus two charged leptons that may have different flavors (see Fig. 1(c)) thus converting the RPC trilepton signal into multileptons [10] with up to seven charged leptons appearing in the final state. Even when the spoiler mode is active, suppressing RPC trileptons, a total of five charged leptons are still present in the decay of $\chi_1^\pm \chi_2^0$ with RPV. Also, the channels $\chi_1^\pm \chi_2^0 \rightarrow (\chi_1^0 \ell^\pm \nu)(\chi_1^0 \nu \nu)$, $\chi_1^\pm \chi_1^0 \rightarrow (\chi_1^0 \ell \nu) \chi_1^0$ or $\chi_1^+ \chi_1^- \rightarrow (\chi_1^0 \ell^+ \nu)(\chi_1^0 \ell'^- \nu)$ give quiet signals with up to five or six leptons. The actual multiplicity of observed leptons depends on the experimental thresholds and angular acceptances; in the present paper we give some sample calculations illustrating the high visibility of these multilepton signals.

In the framework of the minimal supersymmetric standard model (MSSM) with grand

unification (GUTs), the masses and couplings of the charginos χ_i^\pm and neutralinos χ_j^0 are determined by known quantities such as the gauge couplings plus a number of parameters at the SUSY mass scale: (a) the gluino mass $m_{\tilde{g}}$; (b) the Higgsino mass mixing coefficient μ ; (c) the ratio of vacuum expectation values for the two Higgs doublets, $v_2/v_1 = \tan \beta$; (d) the squark masses $m_{\tilde{q}}$ and (e) the CP-odd neutral Higgs mass m_A . Unification constraints on gauge and Yukawa couplings at the GUT scale lead to a greatly reduced parameter set at the SUSY mass scale, through the renormalization group equations (RGE). Such approaches also explain electroweak symmetry breaking as a radiatively induced effect. Recent analyses of the sparticle masses and couplings expected in supergravity models can be found in Refs. [11–16]. A particularly attractive scenario is the occurrence of an infrared fixed point of the top-quark Yukawa coupling [17], which predicts the relation [12]

$$m_t(\text{pole}) \simeq (200 \text{ GeV}) \sin \beta . \quad (2)$$

In the following we adopt this scenario and use the value $m_t = 168$ GeV, for which the RGE solutions of Ref. [13] were constructed, consistent with $m_t = 174 \pm 10^{+13}_{-12}$ GeV from the CDF top-quark candidate events [18]. For this m_t choice $\tan \beta = 1.5$. Our analysis of the chargino and neutralino signatures will be based on Ref. [13] where m_0 and $m_{1/2}$ are input parameters at the GUT scale M_G (along with trilinear couplings $A = 0$ at M_G), obtained with a naturalness condition $|\mu| < 0.5$ TeV on radiative symmetry breaking. The allowed region in $(m_{1/2}, m_0)$ parameter space is shown in Fig. 8 of Ref. [13]. The remaining parameters are determined by the RGE analysis within a twofold ambiguity, corresponding to positive or negative μ .

The fixed-point solution exhibits some simple characteristics, which can be qualitatively understood from the tree-level relationship

$$\frac{1}{2} M_Z^2 = \frac{m_{H_1}^2 - m_{H_2}^2 \tan^2 \beta}{\tan^2 \beta - 1} - \mu^2 . \quad (3)$$

At the electroweak scale, $m_{H_2}^2 \lesssim 0$ and hence $|\mu|$ must be large, and in fact $|\mu|$ is found to be substantially larger than M_2 , the SU(2) gaugino mass. Consequently the \tilde{W} - \tilde{H} mass matrix

is approximately diagonal and the lightest chargino eigenstate χ_1^+ is almost a pure \tilde{W}^+ state. Also, χ_1^0 is nearly a pure U(1) gaugino \tilde{B} while χ_2^0 is almost purely \tilde{W}^0 . A direct result is that the $W^+ \chi_1^- \chi_2^0$ and the $Z \chi_1^+ \chi_1^-$ couplings are almost the maximal gauge couplings, and that the $W^+ \chi_1^- \chi_1^0$ coupling is suppressed (however this suppression may be somewhat offset by more phase space for the light χ_1^0). The dominant production subprocesses $q\bar{q}' \rightarrow W^* \rightarrow \chi_1^+ \chi_2^0$ and $q\bar{q} \rightarrow Z, \gamma \rightarrow \chi_1^+ \chi_1^-$ are then determined mainly by the final state particle masses. The masses of χ_1^0 , χ_2^0 , χ_1^+ , h are illustrated in Fig. 2 versus $m_{1/2}$ for four typical choices of m_0 and the sign of μ . For the case $\mu > 0$ the strongest phenomenological bound comes from the lightest Higgs mass, which is known to be larger than about 60 GeV. As has been emphasized recently [14], radiative corrections are not known very accurately in this case as the tree-level mass is very small, so we indicate this bound with a dashed line. For the case $\mu < 0$ the strongest phenomenological bound comes from the lightest chargino mass, which must be larger than about 45 GeV. There are also weaker bounds coming from the naturalness condition $|\mu| < 0.5$ TeV [13]; taken literally this condition would exclude the higher $m_{1/2}$ ranges in Fig. 2, but since it is somewhat subjective we do not apply it strictly. The production cross sections for $\chi_1^\pm \chi_2^0$, $\chi_1^\pm \chi_1^0$, $\chi_1^+ \chi_1^-$, obtained from the ISAJET program [19], are shown in Fig. 3.

We address the situation where the superpotential contains a possible lepton-number violating term $\lambda_{ijk} L_L^i L_L^j \bar{E}_R^k$ where E_R is the superfield containing the right-handed charged-lepton singlets and L_L contains the lepton doublets; the i, j, k are generation indices. These interactions break R -parity, since they involve an odd number of supersymmetric particles. The Lagrangian generated by this superpotential term has the form

$$\mathcal{L} = \lambda_{ijk} \left[\tilde{\nu}_L^i \tilde{e}_R^k e_L^j + \tilde{e}_L^j \tilde{e}_R^k \nu_L^i + \left(\tilde{e}_R^k \right)^* \left(\tilde{\nu}_L^i \right)^c e_L^j - (i \leftrightarrow j) \right] + \text{h.c.} \quad (4)$$

in four-component Dirac notation. A fundamental RPV interaction of this kind could mediate the decay of any chargino or neutralino, as illustrated in Fig. 1(c) for χ_i^0 . It is natural to assume a hierarchy of interactions such that RPC approximately holds in decays of the heavier gauginos, and RPV is manifest only in the otherwise forbidden decay of the LSP

χ_1^0 . Thus the next stage of our analysis is to evaluate the branching fractions for χ_1^+ and χ_2^0 RPC decays, which can be found using the ISASUSY program [19]. Figure 4 shows that the leptonic $\chi_1^+ \rightarrow \chi_1^0 \ell^+ \nu$ fraction is typically 20–30% (summing $\ell = e, \mu$), which sometimes goes via $\chi_1^0 W^+, \tilde{\ell}^+ \nu$ or $\ell^+ \tilde{\nu}$ on-shell intermediate states. Figure 5 shows that $\chi_2^0 \rightarrow \chi_1^0 \ell \ell$ is often substantial; the branching fraction sometimes depends on intermediate $\tilde{\ell} \ell$ states and sometimes is suppressed due to competition with $\chi_2^0 \rightarrow \chi_1^0 h$, which always dominates when kinematically allowed.

For the RPV effects, we shall assume that the decay leptons do not include τ and that the coupling is strong enough for χ_1^0 to decay near the production vertex, giving a lower limit to the RPV coupling constant [10,20] $\lambda > (\gamma/20)(m_{\tilde{\ell}}/100 \text{ GeV})^2(1 \text{ GeV}/m_{\text{LSP}})^{2.5}$, where γ is the Lorentz boost factor of the LSP and $m_{\tilde{\ell}}$ is the mass of the intermediate slepton in the $\chi_1^0 \rightarrow \ell \ell' \nu$ decay. In our examples below this condition implies $\lambda \gtrsim 10^{-4} \text{--} 10^{-5}$. We also require $\lambda \ll 1$ so that RPV terms do not significantly affect the RGE and existing bounds on the couplings [21] are respected. One obtains the modified RGE at one-loop

$$\frac{d\lambda_{ijk}}{dt} = \frac{\lambda_{ijk}}{16\pi^2} \left[-\frac{9}{5}g_1^2 - 3g_2^2 + (\delta_{j3} + 2\delta_{k3})\lambda_\tau^2 \right] + \frac{1}{16\pi^2} \left[\mathcal{O}(\lambda_{lmn}^3) \right], \quad (5)$$

where λ_{ijk} are the various RPV couplings, and δ_{ij} is the Kronecker delta. The existing bounds [21] require that the λ_{ijk} are small near the electroweak scale, and then from Eq. (5) it follows (for small $\tan \beta$ considered here) that they are small for all scales up to the GUT scale. Consequently the RPV couplings λ_{ijk} have a negligible effect on the lepton Yukawa coupling running and on the running of the soft-supersymmetry breaking parameters. [The situation may be different for the baryon-violating couplings, where the weaker electroweak scale bounds together with the fixed-point character of the associated RGE can yield large baryon-violating couplings near the GUT scale [22]; these couplings must be zero to avoid fast proton decay when lepton-violating couplings are nonzero]. Finally, we have tacitly assumed that the $L_i L_j \bar{E}_k$ terms dominate over possible $L_i Q_j \bar{D}_k$ RPV terms [9,10]; if the latter are not negligible, the LSP can also decay into quarks and the multilepton signals we present here become upper bounds.

For multilepton acceptance we follow Ref. [3] and require rapidity $|y(\ell)| < 2.5$ for all leptons, transverse momentum $p_T(\ell) > 15$ GeV for at least one lepton, $p_T(\ell) > 10$ GeV for the second lepton, and $p_T(\ell) > 8$ GeV for all other observed leptons. In the case of the spoiler mode $\chi_2^0 \rightarrow \chi_1^0 h$, we assume the dominant $h \rightarrow jj$ dijet decay and require all observed leptons to have separations $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} > 0.7$ from both of these jets. These acceptance cuts give a semi-realistic estimate of how many leptons may indeed be observable experimentally. We estimate acceptance factors by Monte Carlo methods, using phase-space decay distributions with full kinematic constraints from intermediate on-shell states.

The following four cases A–D illustrate interesting aspects of the RPC and RPV multilepton signals in the four parameter regions (a)–(d) of Figs. 2–5 above. All cases have $\tan\beta = 1.5$. We sum over lepton flavors $\ell = e, \mu$.

Case A: $m_{1/2} = 110$ GeV, $m_0 = 200$ GeV, $\mu < 0$.

This gives $m(\chi_1^+) = 65$ GeV, $m(\chi_2^0) = 68$ GeV, $m(\chi_1^0) = 34$ GeV, $m(\tilde{g}) = 300$ GeV, $m(h) = 78$ GeV. With RPC there is a straightforward $\chi_1^\pm \chi_2^0 \rightarrow (\chi_1^0 \ell \nu)(\chi_1^0 \ell \ell)$ trilepton signal (no spoiler mode, $\chi_2^0 \not\rightarrow \chi_1^0 h$). With RPV however, these final states give up to 7 leptons; also channels such as $\chi_1^\pm \chi_2^0 \rightarrow (\chi_1^0 \ell \nu)(\chi_1^0 \nu \nu)$ and $\chi_1^\pm \chi_1^0 \rightarrow \chi_1^0 \chi_1^0 \ell \nu$ give up to 5 leptons. Our calculations give the following cross sections σ_n for $\geq n$ leptons to pass acceptance cuts.

$$\begin{aligned}
\text{RPC: } \chi_1^\pm (\chi_2^0 \rightarrow \chi_1^0 \ell \ell) &\Rightarrow \sigma_3 &= 0.03 \text{ pb} ; \\
\text{RPV: } \chi_1^\pm (\chi_2^0 \rightarrow \chi_1^0 \ell \ell) &\Rightarrow \sigma_3, \sigma_4, \sigma_5, \sigma_6, \sigma_7 &= 0.10, 0.08, 0.06, 0.025, 0.005 \text{ pb} ; \\
&\chi_1^\pm (\chi_2^0 \rightarrow \chi_1^0 \nu \nu) \Rightarrow \sigma_3, \sigma_4, \sigma_5 &= 0.15, 0.08, 0.02 \text{ pb} ; \\
&\chi_1^\pm \chi_1^0 \Rightarrow \sigma_3, \sigma_4, \sigma_5 &= 0.19, 0.10, 0.03 \text{ pb} ; \\
&\chi_1^+ \chi_1^- \Rightarrow \sigma_3, \sigma_4, \sigma_5, \sigma_6 &= 0.06, 0.05, 0.02, 0.005 \text{ pb} .
\end{aligned}$$

This demonstrates that RPV can not only enhance the original RPC trilepton channel but can produce quiet multileptons from other channels too.

Case B: $m_{1/2} = 110$ GeV, $m_0 = 50$ GeV, $\mu < 0$.

This gives $m(\chi_1^+) = 58$ GeV, $m(\chi_2^0) = 66$ GeV, $m(\chi_1^0) = 30$ GeV, $m(\tilde{g}) = 300$ GeV, $m(h) = 72$ GeV, $m(\tilde{\ell}_R) = 65$ GeV, so again there is no spoiler mode. However, $\chi_2^0 \rightarrow \chi_1^0 \ell \ell$

decay proceeds almost entirely via $\chi_2^0 \rightarrow \tilde{\ell}\ell$ with $m(\tilde{\ell}) \approx m(\chi_2^0)$, for which one final lepton is very soft and does not pass acceptance cuts, so the RPC trilepton signal almost vanishes.

We obtain

$$\begin{aligned}
 \text{RPC: } \chi_1^\pm(\chi_2^0 \rightarrow \chi_1^0 \ell\ell) \Rightarrow \sigma_3 &= 0.003 \text{ pb} ; \\
 \text{RPV: } \chi_1^\pm(\chi_2^0 \rightarrow \chi_1^0 \ell\ell) \Rightarrow \sigma_3, \sigma_4, \sigma_5, \sigma_6 &= 0.38, 0.28, 0.14, 0.03 \text{ pb} ; \\
 \chi_1^\pm(\chi_2^0 \rightarrow \chi_1^0 \nu\nu) \Rightarrow \sigma_3, \sigma_4, \sigma_5 &= 0.28, 0.14, 0.03 \text{ pb} ; \\
 \chi_1^\pm \chi_1^0 \Rightarrow \sigma_3, \sigma_4, \sigma_5 &= 0.96, 0.43, 0.08 \text{ pb} ; \\
 \chi_1^+ \chi_1^- \Rightarrow \sigma_3, \sigma_4, \sigma_5, \sigma_6 &= 0.24, 0.16, 0.07, 0.01 \text{ pb} .
 \end{aligned}$$

In this example RPV rescues an otherwise suppressed trilepton signal and gives up to 6 final leptons. The biggest RPV signals here come from $\chi_1^\pm \chi_1^0$ production, which exceeds $\chi_1^\pm \chi_2^0$ production in this parameter region (see Fig.3).

Case C: $m_{1/2} = 150$ GeV, $m_0 = 200$ GeV, $\mu > 0$.

This gives $m(\chi_1^+) = 129$ GeV, $m(\chi_2^0) = 129$ GeV, $m(\chi_1^0) = 63$ GeV, $m(\tilde{g}) = 410$ GeV, $m(h) = 61$ GeV, so the spoiler mode $\chi_2^0 \rightarrow \chi_1^0 h$ dominates and suppresses the RPC trilepton signal. However, RPV gives multilepton plus $h \rightarrow jj$ final states from this spoiler mode, and in principle gives quiet multileptons from $\chi_1^\pm \chi_1^0$ and $\chi_1^+ \chi_1^-$ production.

$$\begin{aligned}
 \text{RPC: } \chi_1^\pm(\chi_2^0 \rightarrow \chi_1^0 \ell\ell) \Rightarrow \sigma_3 &\simeq 0 ; \\
 \text{RPV: } \chi_1^\pm(\chi_2^0 \rightarrow \chi_1^0 h) \Rightarrow \sigma_3, \sigma_4, \sigma_5 &= 0.026, 0.017, 0.005 \text{ pb} ; \\
 \chi_1^\pm \chi_1^0 \Rightarrow \sigma_3, \sigma_4, \sigma_5 &= 0.001, 0.001, 0.000 \text{ pb} ; \\
 \chi_1^+ \chi_1^- \Rightarrow \sigma_3, \sigma_4, \sigma_5, \sigma_6 &= 0.005, 0.005, 0.004, 0.002 \text{ pb} .
 \end{aligned}$$

Here RPV rescues the normal spoiler mode. The much smaller multilepton cross sections in this and the following case D (both with $\mu > 0$) are principally due to the much smaller gaugino pair production cross sections; see Fig.3.

Case D: $m_{1/2} = 150$ GeV, $m_0 = 50$ GeV, $\mu > 0$.

This case gives $m(\chi_1^\pm) = 133$ GeV, $m(\chi_2^0) = 133$ GeV, $m(\chi_1^0) = 65$ GeV, $m(\tilde{g}) = 410$ GeV, $m(h) = 59$ GeV, $m(\tilde{\ell}_R) = 77$ GeV, $m(\tilde{\ell}_L) = m(\tilde{\nu}) = 119$ GeV. It is on the edge of being excluded by the m_h experimental bound, but we retain it to illustrate a class of solutions.

Here the spoiler mode $\chi_2^0 \rightarrow \chi_1^0 h$ dominates but $\chi_2^0 \rightarrow \tilde{\ell}\ell \rightarrow \chi_1^0 \ell\ell$ modes manage to compete thanks to the on-shell intermediate state, so the conventional RPC trileptons are only partially suppressed. There is also an appreciable $\chi_2^0 \rightarrow \tilde{\nu}\nu \rightarrow \chi_1^0 \nu\nu$ fraction. The branching fraction $B(\chi_1^+ \rightarrow \tilde{\ell}\nu(\ell\tilde{\nu}) \rightarrow \chi_1^0 \ell\nu) = 0.65$ is remarkably large too. We obtain

$$\begin{aligned}
\text{RPC: } \chi_1^\pm(\chi_2^0 \rightarrow \tilde{\ell}\ell \rightarrow \chi_1^0 \ell\ell) &\Rightarrow \sigma_3 &= 0.003 \text{ pb} ; \\
\text{RPV: } \chi_1^\pm(\chi_2^0 \rightarrow \chi_1^0 h) &\Rightarrow \sigma_3, \sigma_4, \sigma_5 &= 0.027, 0.018, 0.006 \text{ pb} ; \\
\chi_1^\pm(\chi_2^0 \rightarrow \tilde{\ell}\ell \rightarrow \chi_1^0 \ell\ell) &\Rightarrow \sigma_3, \sigma_4, \sigma_5, \sigma_6, \sigma_7 &= 0.005, 0.005, 0.005, 0.004, 0.002 \text{ pb} ; \\
\chi_1^\pm(\chi_2^0 \rightarrow \tilde{\nu}\nu \rightarrow \chi_1^0 \nu\nu) &\Rightarrow \sigma_3, \sigma_4, \sigma_5 &= 0.009, 0.008, 0.004 \text{ pb} ; \\
\chi_1^\pm \chi_1^0 &\Rightarrow \sigma_3, \sigma_4, \sigma_5 &= 0.002, 0.002, 0.001 \text{ pb} ; \\
\chi_1^+ \chi_1^- &\Rightarrow \sigma_3, \sigma_4, \sigma_5, \sigma_6 &= 0.026, 0.025, 0.021, 0.010 \text{ pb} .
\end{aligned}$$

In this example, RPV rescues the dominant spoiler contributions and also gives quiet multileptons in other channels.

These illustrative RPV signals total $\sigma_3 = 0.5, 1.9, 0.03, 0.07$ pb, in cases A, B, C, D respectively, for events with $n \geq 3$ leptons. The recent CDF trilepton search [7], based on 11.1 pb^{-1} luminosity, found just two candidate events; however, their acceptance criteria appear to be more restrictive than ours, and our analysis omits detection-efficiency factors. It is possible therefore that RPV in Case B is already excluded by data, but it still provides an instructive example. Future high-statistics data will put stronger constraints on parameters in the RPV scenario.

To summarize, we have investigated purely leptonic RPV signatures in chargino-neutralino pair production at the Tevatron, using typical SUSY-GUT parameter sets taken from Ref. [13] in the low- $\tan\beta$ fixed-point region. These examples illustrate how RPV decays $\chi_1^0 \rightarrow \ell\ell'\nu$ convert the quiet trilepton production of the RPC scenario into multilepton signals and generate new signals in other final states. In particular they show that

- i) the trilepton rate itself may be greatly enhanced;
- ii) signals with 4 or 5 leptons are typically comparable with the unsuppressed RPC trilepton rate;

- iii) when RPC trileptons are suppressed by the spoiler mode $\chi_2^0 \rightarrow \chi_1^0 h$ or by $\chi_2^0 \rightarrow \tilde{\ell}\ell$ with $m(\tilde{\ell}) \simeq m(\chi_2^0)$, RPV multilepton signals can still be substantial, though some contain $h \rightarrow jj$ dijets;
- iv) substantial quiet RPV multilepton signals can also come from $\chi_1^\pm (\chi_2^0 \rightarrow \chi_1^0 \nu\nu)$, $\chi_1^\pm \chi_1^0$ and $\chi_1^+ \chi_1^-$ channels, that give no RPC trileptons.

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FIGURES

1. Representative diagrams for (a) the pair production of charginos and neutralinos, (b) their RPC decay, and (c) the RPV decay of the lightest neutralino.
2. Masses of the particles in χ_1^+ , χ_2^0 decay cascades, obtained from Ref. [12] for representative GUT-scale inputs. Note that $\tilde{e}_L = \tilde{e}_2$ and $\tilde{e}_R = \tilde{e}_1$ because the mixing angle is negligible.
3. Cross sections for chargino and neutralino pair production at $\sqrt{s} = 1.8$ TeV, for the SUSY-GUT parameters of Fig. 2.
4. Decay branching fractions of the lightest chargino χ_1^+ .
5. Decay branching fractions of the second-lightest neutralino χ_2^0 .

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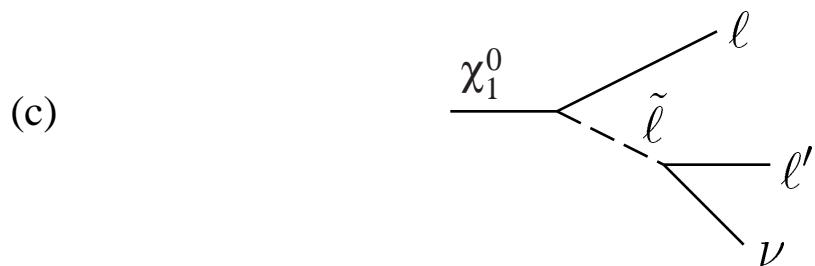
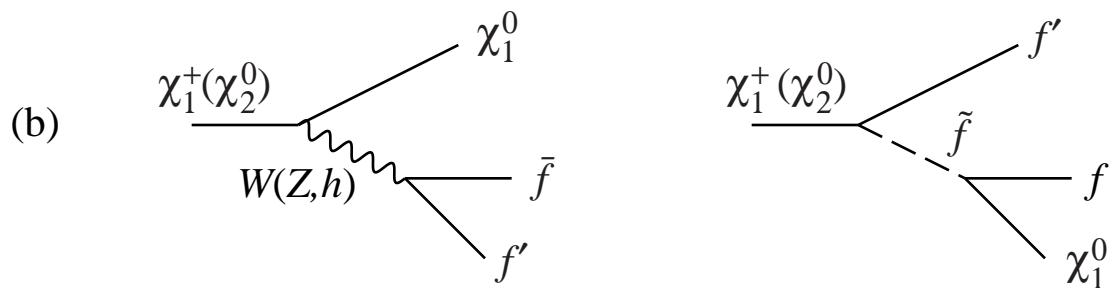
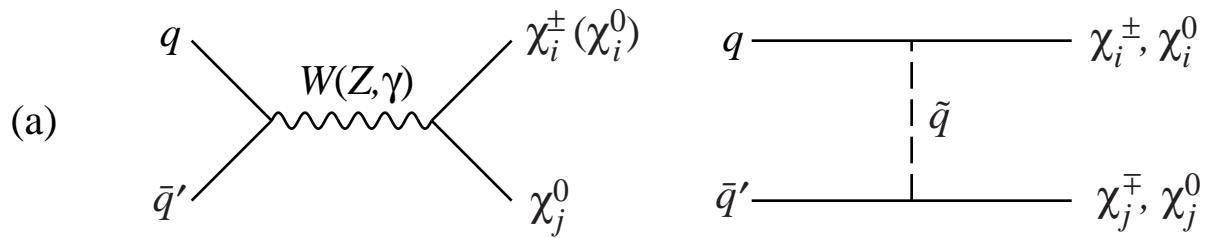


Figure 1

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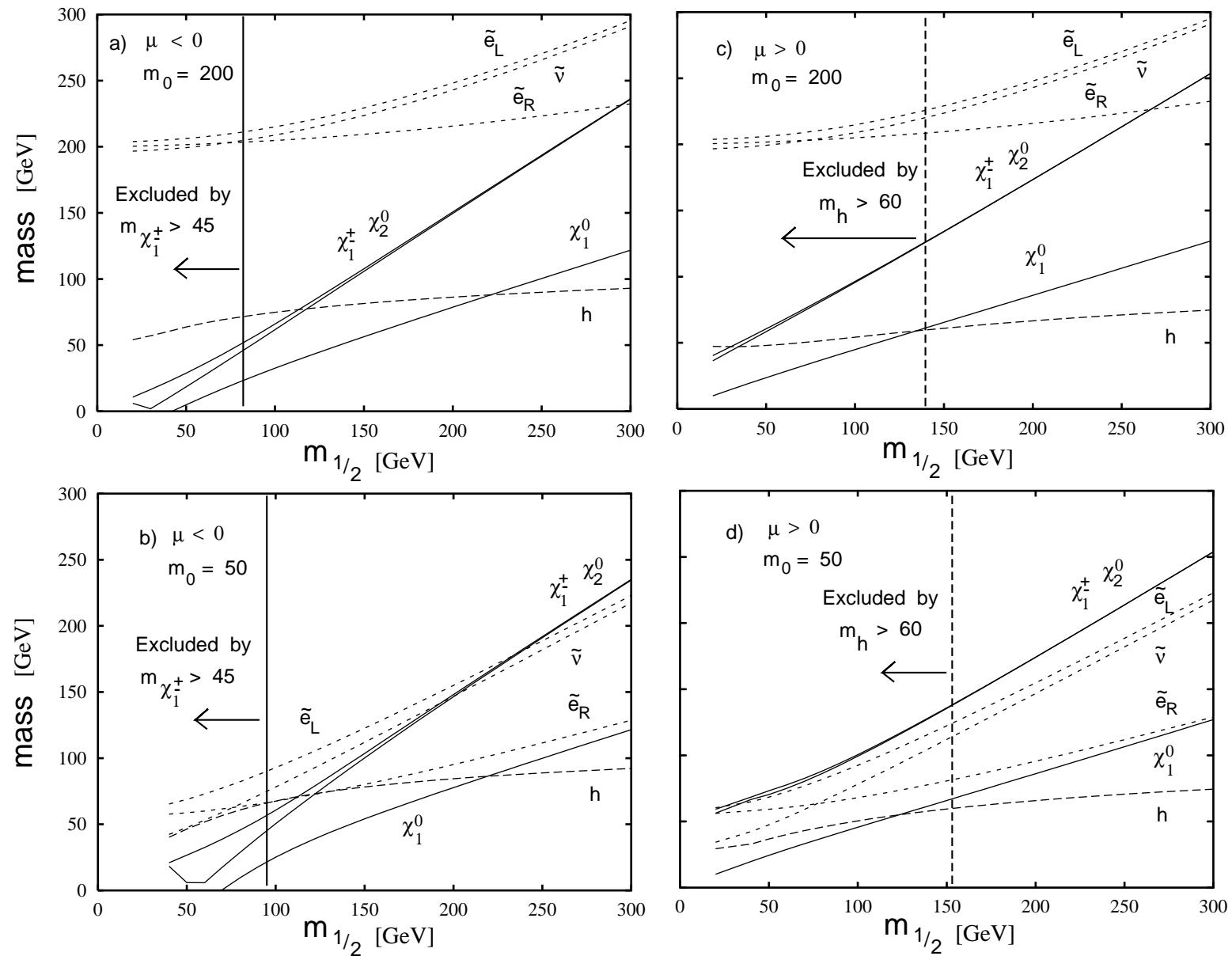


Figure 2

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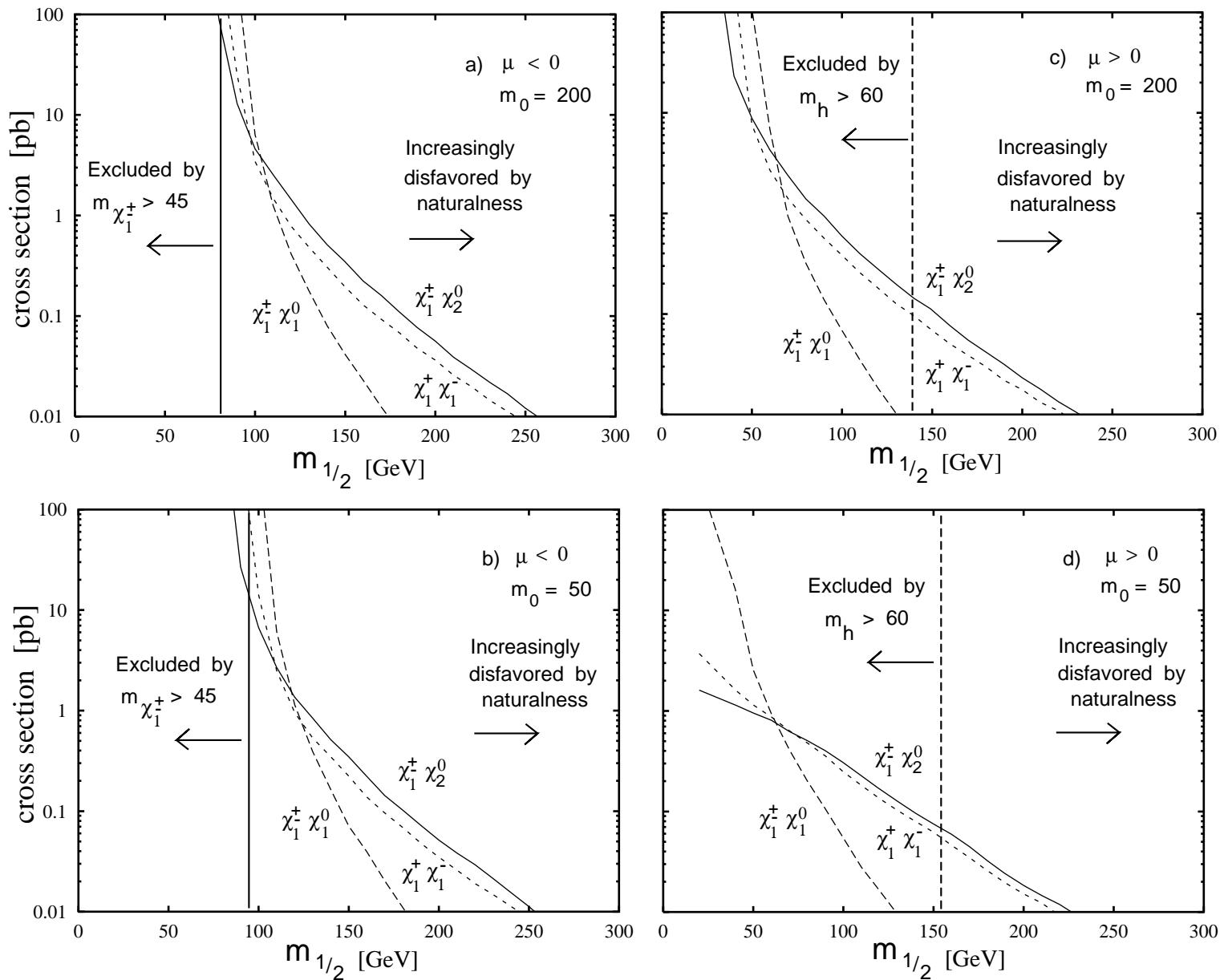


Figure 3

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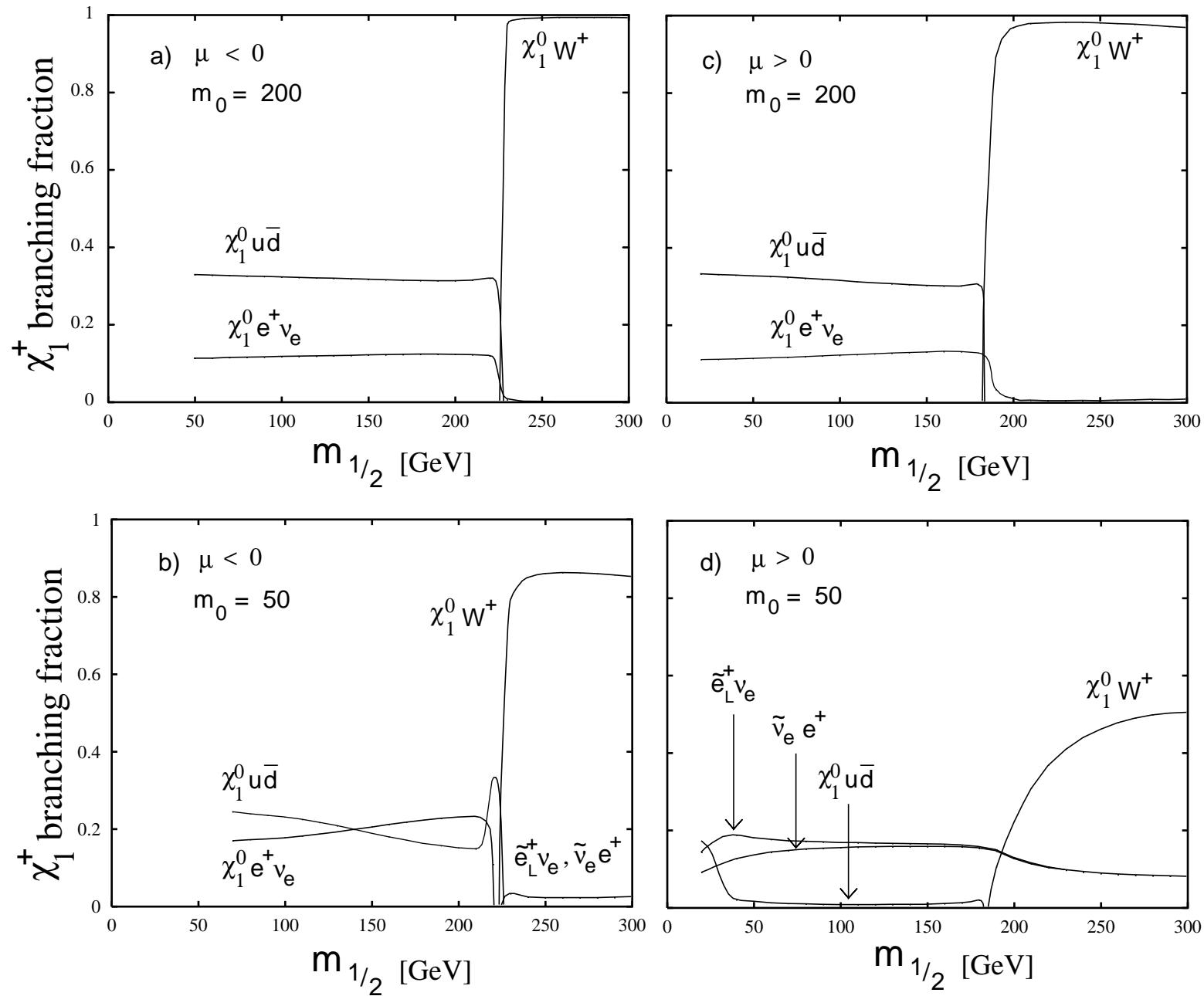


Figure 4

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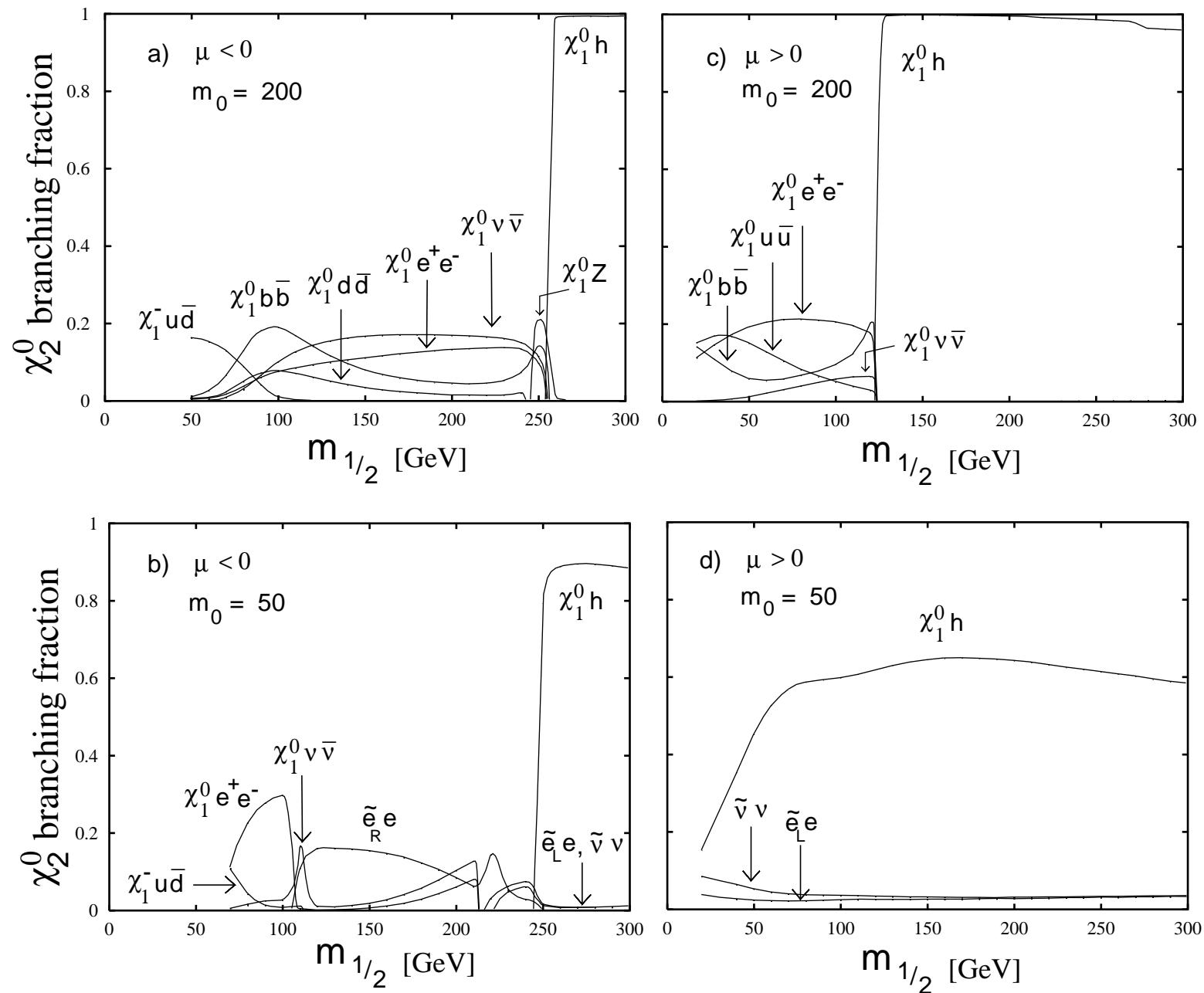


Figure 5